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Space Interferometry Mission

SIM PROJECT
PRELIMINARY INSTRUMENT SYSTEM REQUIREMENTS REVIEW
(PISRR)

SIM SCIENCE

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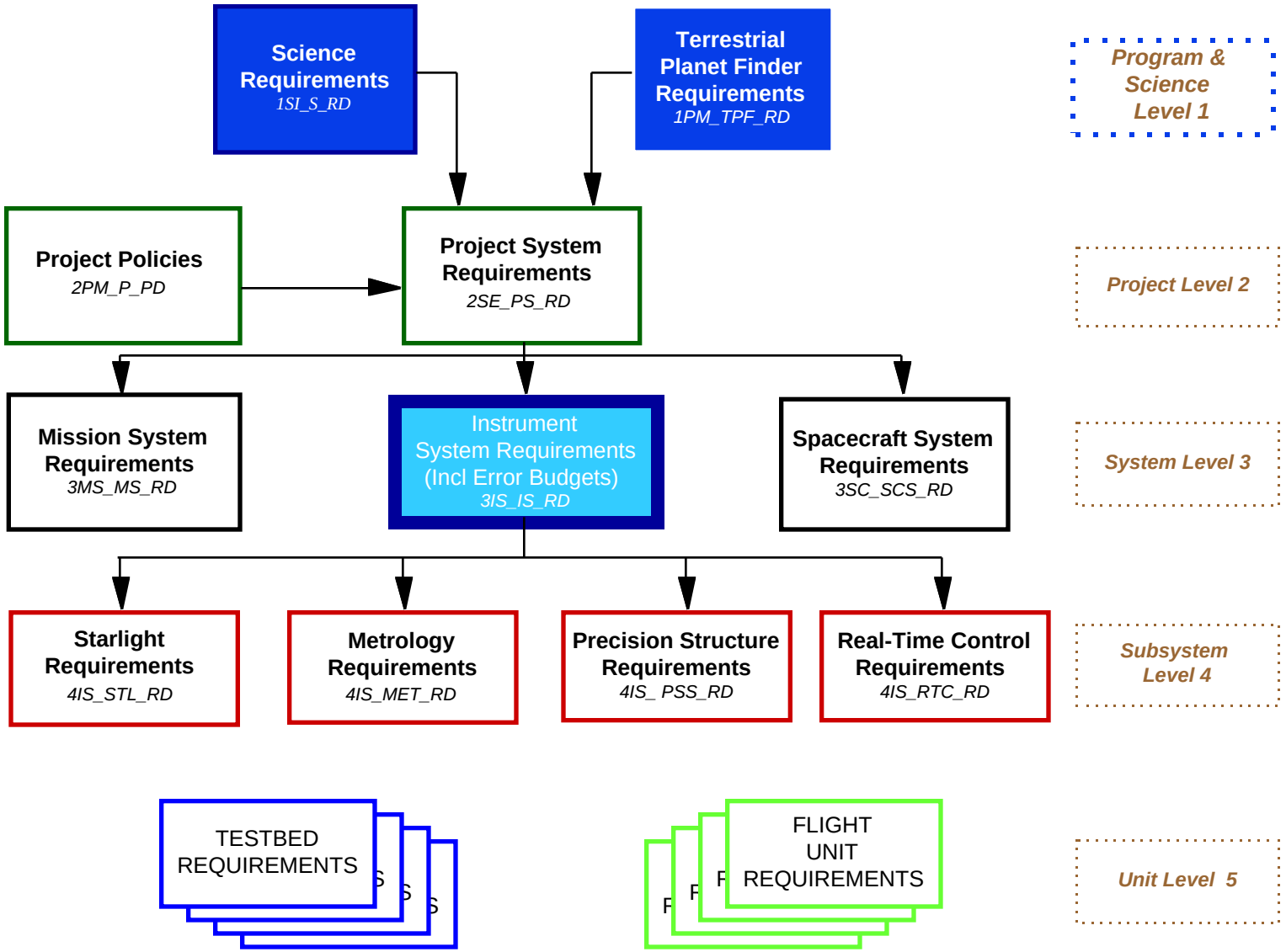
FUNCTIONAL OVERVIEW
REQUIREMENTS FLOWDOWN TREE



DEVELOPMENT OF THE SCIENCE REQUIREMENTS

- Terrestrial Planet Finder (TPF) Requirements
  - SIM shall demonstrate a single-pair nulling beam combiner
    - > TPF will use multiple-collector nulling combiner
  - SIM shall demonstrate nulling a point source to a depth of 10^{-4}
    - > corresponds to a 10^{-6} depth null (at 10 μm) on TPF
    - > error budget includes: OPD jitter, wavefront tilt, polarization leakage, finite star diameter
  - Demonstrate nulling to a depth of 10^{-4} while continuously rotating the science baseline around the line of sight
  - Demonstrate nulling on a V = 7 or brighter star
    - > For V=7 (G0) star, maximum baseline for demo is 1.8m

DEVELOPMENT OF THE SCIENCE REQUIREMENTS (cont.)

- SIM Science Requirements Document has many input sources:
- Responsive to Bahcall (NAS, 1991) "The Decade of Discovery" Report recommendation for an astrometric mission with accuracy in the few μas range
  - Science goals included in Report:
    - > Search for planets around stars within 150 pc
    - > Parallax distances to stars throughout the Galaxy
    - > Demonstrate Technology for future interferometry missions
- JPL and SAO study team reports (1996); several other reports
- Space Interferometry Science Working Group report (1996)
- SIM Science Working Group (3 meetings since September 1996)
  - Develop detailed science program and advise NASA on scientific priorities and MO & DA policies for SIM

SCIENCE OBJECTIVES (Astrometry Examples)

- Search for astrometric signature of planets around nearby stars
  - Jupiter signature detectable out to 1kpc
    - > very large population of candidates
  - Earth signature is 1650 times smaller
    - > detectable only around the closest stars
  - Narrow-angle (local) astrometry; bright targets
- Ages of globular clusters to ~10^9 years
  - Measure distance to cluster, and to calibration stars: sub-dwarfs and RR Lyrae stars
  - Wide angle astrometry; bright targets
- MACHO microlensing events in Galactic bulge and LMC
  - Faint targets; narrow angle astrometry (lens object masses)
  - Faint targets; wide angle astrometry (lens object kinematics)

SCIENCE OBJECTIVES (Astrometry Examples, cont.)

- Rotational parallax distances to spiral galaxies
  - Calibration of Tully-Fisher relation
  - Distances to 5Mpc to 5 %; independent of the conventional cosmic distance 'ladder'
  - Measure *relative* proper motions along major and minor axes of galaxy
  - narrow-angle astrometry mode; faint targets

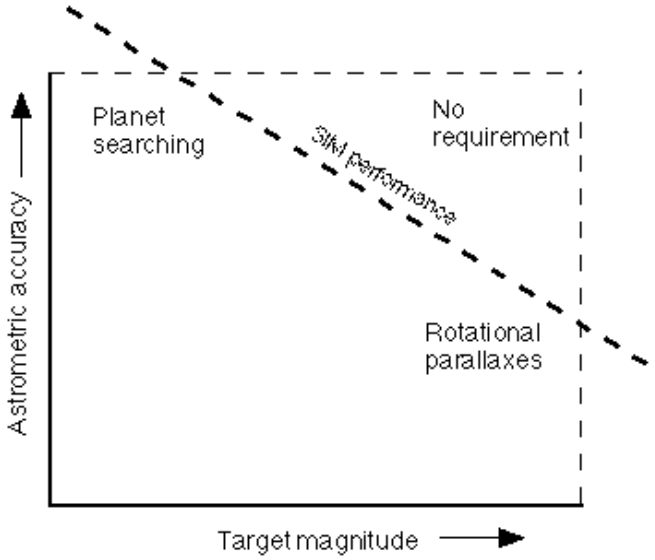
SCIENCE OBJECTIVES (Imaging and Nulling)

- Imaging of emission-line gas around a galactic black hole (e.g. M87)
  - Requires good (u,v) coverage; maximum baseline ~10m
  - Spectral channel width ~ 4nm
  - Integration time ~5 hrs (Hα line is bright)

- Distances to supernovae in external galaxies
  - Supernovae are extremely bright - detectable to large distances
  - Measure angular diameter using nulling, to 10^{-4}
  - Combine with (ground-based) spectral-line velocities to get distance
- Dust disks around young stars (β Pic analogs)
  - Select baseline length to match desired nulled region
  - Null central star to 10^{-4}
  - Detect dust emission within ~ 1 AU of central star

SCIENCE REQUIREMENTS DERIVED FROM SCIENCE OBJECTIVES

- Science objectives translate into:
  - Instrument Requirements
  - Mission Ops Requirements
  - Science Data Analysis Requirements
- Note: Science objectives challenge the performance in different ways. Almost none place extreme demands in every area
- Example: Astrometric detection of earth-like planets
  - Requires highest possible narrow-angle accuracy
  - but:
    - > all targets are bright (V < 10)
    - > does not require absolute positions or parallaxes



SUMMARY OF SCIENCE REQUIREMENTS
(For Science 'goals' and science 'floor', see SRD)

- Overall System Requirements
  - Observational Band: 400 - 1000 nm
    - > for observability of stars of a wide range of spectral types
  - Sky coverage: All-sky
    - > no permanently inaccessible regions
  - 3-D spacecraft velocity knowledge: 4 mm /s
    - > differential aberration across a tile equivalent to 0.7 μas
  - Target accessibility for astrometry: 6 months
    - > optimize parallax sensitivity
  - Target accessibility for imaging: annual window
    - > no permanently inaccessible regions
  - Sun exclusion zone: <=60°
    - > Minimize for response to TOOs; binary orbits, etc.
  - Mission lifetime: 5 years
    - > optimize proper motions and wide-orbit binaries

SUMMARY OF SCIENCE REQUIREMENTS (refer to the SRD for details)

- Overall Operations Requirements
  - RA / dec error ratio $E_{\alpha\delta}$: $1.1 > |E_{\alpha\delta}| > 0.9$ (mission)
    - > Astrometric grid closure; binary orbit solutions
    - > No requirement on PA of individual 1-D measurements
  - Targets of Opportunity response time:
    - > within 4 days of receipt (SIMSWG to set exact number)
- Global astrometric grid observation requirements
    - > These requirements are developed via grid obs simulation, including a simple instrument model
  - Observations dedicated to development of astrometric grid shall not exceed 30% of the available mission timeline
  - 'Tile' overlap pattern shall not be repeated on successive grid campaigns ('orange peels')
  - Minimization of correlated (zonal) errors requires:
    - > Minimum instrument FOR 15°
    - > Maximum Sun exclusion angle 60°

Instrument Performance Requirements
Global astrometry

- Global astrometry defined as science observations which require the 4-π astrometric grid
- Science observations are 'tied' to nearby grid stars within a 'tile'
  - Most programs (and all absolute parallaxes) need the grid
- Mission accuracy requirement (position): 4 μas
- Mission accuracy requirement (proper motion): 1 μas / yr
  - single measurement accuracy: 10.5 μas
  - (single measurement) / (global accuracy) > 2.6
    - > primarily a mission ops. requirement
    - > from grid campaign simulations
  - Astrometry sensitivity requirement: V = 20.0 star
    - > error contribution from photon-counts: 7.0 μas
    - > on-source time required: 3.9 hours
      - Scales as √(star brightness x time) for faint targets
      - Long integrations may be done piecewise

Instrument Performance Requirements
Local astrometry

- Local (narrow-angle) astrometry defined to be astrometry which does *not* require the 4-π astrometric grid
- Narrow-angle defined to be: 1° diameter
- Single measurement accuracy: 1 μas
  - typically, sequence of short observations during ~1 hour
- Astrometry sensitivity requirement: V = 12.5 star
  - error contribution from photon-counts: 1.5 μas
  - on-source time required: 300 seconds
- Mission accuracy: 0.25 μas
  - repeated measurements to target
  - number and timing of measurements depends on science objective

Instrument Performance Requirements
Synthesis Imaging

- SIM shall form images using aperture synthesis technique
- Angular resolution (at 600nm) 10 mas
- Imaging fidelity requires
  - Good (u,v) coverage
  - Good amplitude and phase calibration
  - Adequate SNR in the (u,v) data
    - > Fidelity is a *very* complicated function of these quantities
- Imaging sensitivity
  - Specify in terms of a simple point-source target:
  - Star brightness (unresolved, single pixel) V = 20
  - SNR in (single) image pixel 10
  - on-source integration time: < 70 seconds

Instrument Performance Requirements
Synthesis Imaging (cont.)

- (u,v) Coverage
  - Maximum baseline 10m
  - Minimum baseline 0.5m
  - Baseline step size 0.5m
  - Maximum 'hole' size in (u,v) plane 0.5m
- Fringe V^2 calibration (of each u,v point) 1 %
  - Overall flux scale error 5 %
- Fringe Phase calibration 1.8°
  - relative to a phase reference position in field
- Imaging field size: 0.4 arcsec
  - limited by field stop
- Spectral resolution (across 400-1000nm) 100 channels
  - Required for spectral imaging
  - Not required for continuum imaging (e.g. starlight, dust)

Instrument Performance Requirements
Interferometric Nulling

- Requirements are derived from TPF Requirements
- Nulled *images* require, in addition:
  - Observations at several baseline position angles
  - Observations at several baseline lengths
  - Fringe amplitude calibration (of each nulled u,v point) ~15 %
    - > Overall flux scale error ~25 %
    - > Fringe phase calibration N / A

CONCERNS SUMMARY

- SIMSWG has not completed the definition of science requirements or the science goals
- Prioritization of science requirements is needed
- Interaction of science objectives with instrument performance and observing scenario is very complicated, and requires further simulation
- Grid campaign simulations require better fidelity
  - simulation accuracy depends strongly on assumptions
    - > in instrument model
    - > grid observing scenario (‘orange peels’)

CONCLUDING REMARKS

- SIM will revolutionize astrometry!
  - The full scientific implications of the Hipparcos mission are only now being appreciated
  - SIM will yield accurate distances out to 250 times as far as Hipparcos could provide
  - SIM's science capability will be unique
- Synthesis imaging with SIM will provide high dynamic range, high resolution imaging of bright targets
- Nulling is a crucial technology demonstration for future missions, and may yield significant science